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MANAGING AGING IN NUCLEAR POWER PLANTS: INSIGHTS FROM NRC'S MAINTENANCE TEAM INSPECTION REPORTS[1]

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Abstract

A plant's maintenance program is the principal vehicle through which age-related degradation is managed. From 1988 to 1991, the NRC evaluated the maintenance program of every nuclear power plant in the United States. Forty-four out of a total of sixty-seven of the reports issued on these in-depth team inspections have been reviewed for insights into the strengths and weaknesses of the programs as related to the need to understand and manage the effects of aging on nuclear plant structures, systems, and components (SSCs). Relevant information has been extracted from these inspection reports sorted into several categories; including Specific Aging Insights, Preventive Maintenance, Predictive Maintenance and Condition Monitoring, Post Maintenance Testing, Failure Trending, Root Cause Analysis and Usage of Probabilistic Risk Assessment in the Maintenance Process. Specific examples of inspection and monitoring techniques successfully used by utilities to detect degradation due to aging have been identified.

The information was also sorted according to systems and components. The systems include: auxiliary feedwater, main feedwater, high pressure injection for both BWRs and PWRs, service water, instrument air, and emergency diesel generator air start systems. The components include: emergency diesel generators, electrical components, such as switchgears, breakers, relays, and motor control centers, motor operated valves and check valves. The information for systems and components was compared to that obtained from the individual NPAR system- and component-level studies.

Results from this study indicated that, while some plant organizations appear to assume a proactive stance in preventing aging-related failures of their SSCs important to safety, others seem to be taking a passive or reactive stance. Differing maintenance philosophies and financial resources have an impact on plant management's attention to aging concerns. It does not apprear that any utility has a separate and distinct program specifically addressing the management of aging. Such a program is not necessary because all plants have infrastructures in place that can deal with the effects of aging. What is needed is a recognition of the importance of aging related degradation and a commitment to use existing organizational assets to detect and mitigate these effects. This paper outlines some of the human performance factors which should be considered for improvement to enable the understanding, detection, and mitigation of the effects of aging.

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Introduction

Assuring the safe operation of a nuclear power plant depends, to a large extent, on how effectively one understands and manages the aging-related degradation that occurs in structures, systems, and components (SSCs). During the plant's original licensing process, the utilities and the NRC use all available sources including equipment qualification (EQ) results, industry standards and practices, and vendor recommendations, to ensure that, during the life of a plant, all SSCs remain able to accomplish their design functions. Utility EQ programs establish requirements for selected safety-related SSCs, and outline operational and maintenance practices that should prevent any such failure during the life of the plant. These practices include periodic testing and inspection, replacement and refurbishment, condition monitoring, trending, reconditioning and lubricating, and performing advanced testing for early detection of incipient failures.

After over two decades of experience, the commercial nuclear power industry has many sources of information, such as regular NRC inspections, 10 CFR Part 21 reports by vendors, NRC Generic Letters, Bulletins, Information Notices, and research activities, including the Nuclear Plant Aging Research (NPAR) program. These sources have indicated that failures of SCCs, even safety-related items, do occur in spite of all the activities imposed by the original licensing requirements. In recognition of this fact, the NRC implemented a team inspection program to evaluate and assess the current maintenance practices in place at all nuclear power plant facilities.

From 1988 to 1991, the staff of the Nuclear Regulatory Commission conducted Maintenance Team Inspections (MTIs) at commercial nuclear power plants to evaluate the effectiveness of licensee maintenance activities and to determine the need for a maintenance rule. The inspections were performance based, directed toward evaluating equipment conditions; observing in-process maintenance activities; reviewing equipment histories and records; and evaluating performance indicators, maintenance control procedures, and the overall maintenance program. The team selected certain systems and directed the inspection toward determining whether those systems were being properly maintained. In addition, the team assessed if the current maintenance activities would ensure proper function in the remaining life of the plant.

There are a total of 67 MTI reports, one for each site. For the purpose of this research, a representative sample of 44 reports, which were issued through the end of 1990 and were readily available for our study, was selected. These 44 reports correspond to 29 Westinghouse PWR units, 16 Combustion Engineering PWR units, one Babcock & Wilcox PWR unit, and 22 General Electric BWR units. The reports themselves are comprehensive documents, some of which may be 70 or more pages long. Most, if not all, were prepared by different teams of NRC inspectors so that the same team usually did not perform more than one inspection. The inspections were conducted using the guidance provided in NRC Temporary Instruction 2515/97, "Maintenance Inspection Guide," dated November 3, 1988, which includes a Maintenance Inspection Tree. The selection of systems inspected was also different from one report to another.

Methodology

The major areas of utility maintenance programs which were evaluated by the NRC included (a) Overall Plant Performance Related to Maintenance, (b) Management Support of Maintenance, and (c) Maintenance Implementation. Diverse information reflecting the following aging related elements were compiled and sorted:

i. Specific aging-related insights or management responsiveness to aging concerns,
ii. Preventive maintenance and incorporation of manufacturers' recommendations,
iii. Predictive maintenance and condition monitoring techniques,
iv. Post maintenance testing,
v. Failure trending analysis,
vi. Root cause analysis or failure analysis, and
vii. Use of Probabilistic Risk Analysis (PRA) in the maintenance programs.

Findings in these seven broad categories were based on the evaluation of the entire MTI report in the light of their (a) positive aspects or attributes, (b) observation of neutral aspects, (c) negative aspect or deficiency, (d) failure, usually a direct reference to a specific system or component, and (e) violations identified by the NRC staff.

This study was limited to an evaluation of the MTI reports issued by the NRC as a result of their site inspection of nuclear power plant facilities. No attempt was made to discuss any of the findings either with the NRC inspectors or the utility personnel. Utility rebuttals to the original MTI reports and NRC re-inspection at certain plants were not considered as well. Because of the nature of these MTI reports, the process of selecting systems at a particular site, and the inspection process itself, the following conditions should be considered while interpreting the results presented in this paper:

(1) As a result of previously known problems and problems identified during the inspection, the NRC inspection teams placed different emphasis on some topics at one plant as compared to another plant. As a result of the specific inspection requirements of each plant; the MTI reports vary significantly in emphasis and detail placed on particular topics.

(2) A typical MTI report describes both positive and negative aspects of a utility's maintenance program. However, in the majority of cases, the negative aspects are described in greater detail. Positive aspects are often described in general terms and may be broad statements on a major topic.

(3) It was sometimes difficult to differentiate between positive aspects and observations or between deficiencies and observations. Sometimes an NRC inspector merely described the aspects of a program without indicating whether it was considered to be positive or negative.

(4) One MTI report was generated for each site.. Some sites are multi-unit, and the reactor types may also be completely different from one unit to the next. For data analysis purposes, because we often could not determine specifically which unit the NRC inspectors were referring to, the multi-unit sites with different reactor types were counted under each reactor type.

With proper consideration of the above, the quantitative data provide very limited insights into the effects of maintenance on aging-related degradation. The data did not show any clear relationship to the age of the plants and no firm conclusions can be drawn from the data set. However, the large database of textual information was extracted and evaluated to present in a perspective useful to those concerned with the management of aging-related degradation of SSCs in nuclear power plants. The information lends itself more to qualitative rather than quantitative evaluation; therefore, the focus of this paper is on providing qualitative assessments of the programatic areas, and on discussing this same information from a system and component perspective.

Based on the results from this evaluation, an attempt is made to define effective aging management practices. The research recommendations from the NPAR studies on various SSCs provide a basic technical foundation in understanding, detecting, and mitigating aging related problems. Since a plant's maintenance program is the principal vehicle through which aging-related degradation is managed, this paper describes some of the management and organizational (M&O) factors which should be considered to implement each of the activities required in managing the effects of aging. Since all plants have infrastructures in place that can deal with the effects of aging, these M&O factors can heighten utility awareness of the importance of aging related degradation and of the use of existing organizational assets to effectively detect and mitigate their effects.

Programmatic Insights

The programmatic aspects of effective aging management practices include (1) a clear understanding and recognition of aging of SSCs, (2) identification of effective aging management practices that should be able to detect and mitigate the effects of aging at an incipient stage, and (3) management and organization attentiveness to aging. The following discussions provide some of the characteristics of the status of the programmatic efforts by the utilities:

Specific Aging Insights

In general, the MTI reports provide substantial information on how plant maintenance programs address the aging of SSCs. This includes the attitude of management toward the aging issues and specific program attributes which address the detection or mitigation of degradation caused by aging.

While some utilities appeared to assume a proactive stance to prevent aging-related failures of SSCs important to safety, others seemed to be taking a passive or reactive stance. Differing maintenance philosophies and financial resources affect management's attention to aging concerns. One utility considered its license renewal program be founded upon a strong maintenance program. None of the utilities had a separate or distinct program to address the management of aging. Most, if not all, appeared to rely on their maintenance programs to indirectly address aging.

The activities at every plant assure that the infrastructure for understanding the aging problems exists in the operational and maintenance (O&M) programs of the plant. Recent studies on nuclear plant aging, case studies on certain components and systems, and other related research activities both by the industry and the NRC have created an awareness among the utilities on aging of structures, systems,and components in nuclear power plants. This is evident from their adoption of programs such as Reliability Centered Maintenance (RCM) and Life Cycle Management (LCM). Some plants have implemented advanced techniques to manage aging, which includes vibration monitoring, thermography, Electronic Characterization and Diagnostics (ECAD), and other testing and monitoring methods. There are areas noted for improvement with respect to management of aging in the present plant maintenance programs. In summary, the overall impression after reviewing the 44 MTI reports is that taking a forward looking approach to the management of aging is in the initial stages.

Aging Management Program Insights

PREVENTIVE MAINTENANCE: Preventive Maintenance (PM) is the periodic, predictive, or planned maintenance of a SSC, which is performed before failure, to extend the service life by controlling degradation or failure. Every plant has a PM program as part of their plant maintenance program, specifically for those that are vital to plant safety and for power generation. The PM program involves scheduled inspection activities for observing the equipment conditions, monitoring and surveillance testing of various equipment functional parameters, replacement of degraded parts or parts with known life cycles, and routine maintenance activities such as cleaning, repacking, and lubricating.

Strictly speaking, predictive maintenance is the term which should be applied to diagnostic practices such as scheduled inservice inspection and testing (ISI/IST) that are required by the ASME Code Section XI and plant technical specifications.

A number of activities cited in the MTI reports suggest that the industry is striving to improve their existing PM programs. Most original PM program elements are developed in response to regulatory requirements, vendor recommendations and good practices. Especially noteworthy are 13-week rolling maintenance schedules at a few plants in which an entire train of safety-related components taken out of service for maintenance and surveillance testing. A Configuration Management Information System (CMIS) has been implemented at a few plants to enhance the effectiveness of the PM program. Other efforts include adopting improved testing methods, monitoring performance of the entire plant or certain systems in addition to individual equipment, trending of maintenance data, root cause analysis, scram frequency analysis, and material condition management programs. Other analytical approaches include time series analysis of equipment failures, improved MOV reliability, and aggressive resolution of immediate problems.

Many of the activities mentioned above are not focussed to identify age-related deterioration occuring in the equipment. Rather the PMs are performed to keep the component operable so as not to compromise plant availability. Some PM schedules have not been implemented on a timely basis and in fact, have items long overdue. In some cases, often without adequate justification, certain components, such as molded case circuit breakers and instrument air system filters, were not subjected to PM for long intervals. Backlogs for PM were high at some plants.

As the benefits of a good PM program become evident, additional components are often added to the list for vibration monitoring, oil sampling, and periodic cycling. The PM frequencies chosen for particular equipment types are not uniform throughout the industry. The frequencies are usually based on good maintenance practices, vendor recommendations, component failure experience, outage planning and management decisions regarding financial and staffing resources.

PREDICTIVE MAINTENANCE AND CONDITION MONITORING: Predictive maintenance and condition monitoring include diagnostic practices which can be useful to predict the remaining life to assure the operational readiness until the next scheduled maintenance, and to detect incipient degradation due to the effects of aging. The most common practices include trending of degradation and failure rates, thermography, signature analysis of MOVs, and vibration analysis. From the available information, it was difficult to compare one utility's predictive programs to another's. However, many utilities perform similar condition monitoring programs, specifically valve surveillance testing using MOVATS(Motor Operated Valve Analysis and Test System) or VOTES(Valve Operation Test Evaluation System), lubrication /oil analysis, vibration monitoring and infrared imaging of intricate electrical circuits. Especially noteworthy was the microelectronic surveillance and calibration (MESAC) system at the Braidwood station to dynamically test instrument systems. Use of advanced techniques is still in the early stages of implementation at most plants and an increasing trend of usage of such techniques is evident from the MTI reports.

Remaining life assessment of equipment is done qualitatively based on the information available from the EQ test or analysis programs, good maintenance practices in other industries, vendor recommendations, and operating experience. IEEE standards are used to predict remaining life based on the Arrhenius methodology. The overall performance of equipment is often characterized by the useful life of the weakest subcomponent.

POST-MAINTENANCE TESTING: Post-maintenance testing (PMT), as the name implies, is an activity or a number of activities that assures the operational readiness of a component or a system after appropriate maintenance (PM or CM) is performed to monitor age-related degradation or to retore it to its normal operating condition. PMT is also referred to as operations verification testing, functional testing, channel checking, or time-delay testing, depending on the application to a particular component or a system. This activity is sometimes implemented at the next surveillance test. Otherwise it may involve inspection checking,or just operating the equipment. In some cases, although these activities are very well documented and comprehensive in scope, acceptance criteria to confirm the operational readiness are very limited and vague. The manufacturers often may not be able to define the thresholds which signify that the degree of degradation is unacceptable.

Human-related problems have been discovered during PMT and appropriate actions are taken to restore the equipment conditions. Sometimes the PMT activity itself has resulted in corrective maintenance. If the PMT does not identify ineffective maintenance, then aging can occur faster than expected. Thus, the effectiveness of the maintenance can be measured by the success of the PMT. Documentation of PMT results was often poor. While examples of well-documented and implemented PMT programs were cited in the reports, the overall impression is that PMT is an area that requires significant improvement at many plants.

TRENDING ANALYSIS: Trending analysis is the evaluation of the statistical pattern of performance indicators over a period of time. These indicators are typically available from records of certain plant activities including maintenance work requests and component/system functional or design parameters. A number of computer-based software programs are used by almost all plants. Newer plants have an easier task to implement a trending program than the older facilities, since they have the benefit of starting the data collection process in a trendable form early in plant life. Although a large number plants seem to have trending programs in place as part of their maintenance programs, because of the inadequacies of the records and lack of commitment to trend the observed failures, these programs are not adequate for understanding, detecting and mitigating the effects of aging.

ROOT CAUSE ANALYSIS: Root cause analysis (RCA) is the in-depth evaluation of the causes and mechanisms of a failure event so that repetitive occurrence of this event can be prevented or minimized and thus, maintenance backlogs and equipment outage time can be reduced. Inadequate analysis, inadequate support from the engineering support staff, insufficient information available for the RCA, and lack of commitment on the part of the management are among some of the deficiencies noted from this study. A couple of plants, in contrast, have demonstrated cases of very well performed and documented RCA for battery chargers and MSIVs(main steam isolation valves). The overall impression is that RCA is an area not totally appreciated by all utilities and hence an area which requires significant improvement.

USE OF PROBABILISTIC RISK ASSESSMENT: Probabilistic Risk Assessment (PRA) has not been extensively used in the maintenance decisions. Only a few utilities use PRA for higher level decision making such as scheduling system outages, justifying limiting conditions of operations, determining the importance of implementing modification, and prioritizing their order of implementation. Use of PRA for maintenance decision-making is still in the development stages.

System/Component-Level Insights

A number of systems and components were chosen for this study to compare the kinds of maintenance practices being performed at the nuclear power plant facilities with the results and recommendations obtained from the NRC's aging studies. The ssystems chosen were auxiliary feedwater, feedwater, high pressure injection, service water, and instrument air and emergency diesel generator air start systems and compressors. The components chosen were emergency diesel generators, electrical components (breakers, switchgears, relays and motor control centers), motor-operated valves and check valves.

This evaluation also provides a very useful alternative perspective. It yields a qualitative understanding of aging problems pertaining to specific systems or components. Examples of strengths and weaknesses in specific plant maintenance programs are also discussed. For the purpose of presentation, results for the service water system and the check valves are discussed below.

Service Water System

Service Water Systems (SWSs) perform vital safety functions, as the final link between the reactor and the ultimate heat sink (i.e. river, lake, cooling pond,etc.). Based on operating experience, corrosion, biofouling, and wear are the principal degradation mechanisms for SWS aging problems. NRC Generic Letter 89-13 concerning biofouling of safety-related equipment and an AEOD study have generated an awareness among the utilities of the problems associated with this system. Aging insights from the MTI reports include thinning of pipe wall due to erosion/corrosion, resulting in through-wall leaks at the welded joints of carbon steel, absence of chemical treatment of spray ponds resulting in valves and piping becoming filled with scale and sludge, chloride-induced stress corrosion, pump seal and packing leaks, accumulation of dirt at relay and switch contacts, and water hammer problems causing system vibration. Most utilities are aware of these problems, as applicable to their plants. However, poor maintenance practices, lack of incorporation of industry-recommended practices, and inadequate root cause analysis are among the problems which have promulgated SWS failures.

Since this system is a highly important, safety-related system, the components within the system are often subjected to a PM program, as is the case for other safety systems. However, the system uses raw water from an outside source, which is typically very harsh and causes deterioration of components faster than expected. Again, its continuous operating status during the plant's normal operation accelerates the aging process even further. Utilities are chemically treating the water to prevent corrosion and taking other preventive measures to avoid microbiologically-influenced corrosion. Generally, the MTI reports suggested that while there were many examples of inadequate maintenance activities, utilities are conscious of the problems associated with this system.

Check Valves

The function of a check valve is simply to open to permit flow in one direction and to close to prevent flow in the other direction. Most check valves are self-actuating; that is, they require no external mechanical or electrical signal to either open or close. Since 1980, numerous NRC activities have identified problems and recommended appropriate courses of action associated with these valves. Typical age-related degradation mechanisms include pitting, erosion/corrosion of valve body, loose springs, damaged rubber seat, leaking valves, stuck open disc, and blockage of flow path due to boric acid accumulation. Cases were noted where corrosion and separation of the hinge pins, hinge arms, discs, and disc nut pins resulting from the turbulent flow of fluid had caused check valves to fail prematurely. In response to the NRC and INPO notices, some plants have intensified their check valve maintenance programs. Refurbishment and replacement of valve components, use of acoustics for monitoring valve performances, known as Acoustic Emission Monitoring (AEM) program, and improved PM programs including periodic inspection, leak testing and stroke testing are among some of the activities that are used to manage aging in check valves.

Effective Aging Management

Effective aging management practices at a nuclear facility require consideration of both technical and management and organizational (M&O) factors that are important for understanding, detecting, and mitigating the effects of aging. The identification of the technical needs for developing such programs are presented in the NPAR studies on SSCs, as well as several other case studies by the NRC and the nuclear industry. The results from this research indicate that there exists no separate and distinct program specifically addressing the management of aging. The following discussions provide a framework that integrates both the above elements to enhance the existing plant maintenance practices for effectively managing the effects of aging.

One of the most important elements for developing successful aging management practices is the support and commitment from utility management. The support includes, as an objective, achieving a better and effective plant operation, and a strong financial and resource commitment. In return, the plant's maintenance program assures that modifications to the existing programs are cost-effective in the sense of effective aging management, while the plant will continue to operate safely and reliably. The changes necessary for optimal management of aging include activities that are encompassed within several categories of M&O factors.

In a typical aging management program, either (1) a number of systems are selected which are important for reliable and safe plant operation or (2) a number of component types are selected whose maintenance improvement can enhance plant performance in many key systems. Based on the aging studies and various case studies on these items performed by the AEOD, EPRI, and utilities, the technical improvements in understanding, detecting, and mitigating aging problems are correlated to a plant's existing maintenance programs for each of the programmatic categories discussed earlier. Interviews and functional assessment of the facility's day-to-day activities are then performed to understand the operational modes in the following M&O areas:

- Communication
- Standardization of work and skill
- Human resources
- Cultural awareness
- Decision-making
- Organizational skills.

Each of these factors have subelements directly or indirectly related to implementing the technical improvements into the existing maintenance programs. The overall performance of a plant in detecting and mitigating aging is then measured by evaluating the information obtained from all of the above areas of activities. A system-level or component-level reliability assessment is required based on the recommended changes, to fine tune the scope of these activities to achieve the initial goals set by top management.

Conclusions

The NRC teams evaluated maintenance programs through a systematic approach using management oversight and risk-tree (MORT) analysis. Several areas of review are related to how a plant understands and manages the effects of aging. This evaluation of the 44 MTI reports indicate that weaknesses exist in some portions of maintenance programs deemed important for understanding and managing aging, while others are strong or in the process of being strengthened. However, even though a site's maintenance program may receive an overall good or satisfactory rating, it does not necessarily follow that concerns related to aging-related degradation are being satisfactorily addressed. Clearly, if a site's program has a poor rating, aging-related degradation concerns cannot be satisfactorily addressed.

The strongest conclusion that can be drawn from this evaluation is that improvements in preventive and predictive maintenance programs, including failure trending and root cause analysis, together with the development of an integrated maintenance database, can significantly improve the management of aging degradation and the safety of nuclear plant operations. This paper has identified the strengths and weaknesses of some of the programmatic and system/component aging management programs that are available in the NRC's MTI reports.

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